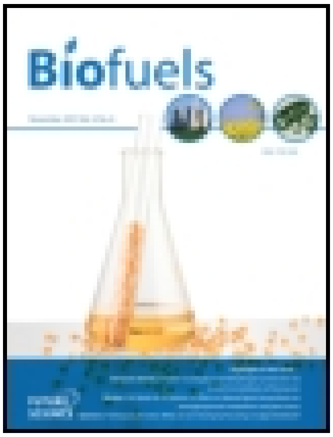

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Optimizing hammer mill performance through screen selection and hammer design

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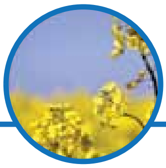


Neal Yancey*, Christopher T Wright & Tyler L Westover

Background: Mechanical preprocessing, which includes particle-size reduction and mechanical separation, is one of the primary operations in the feedstock supply system for a lignocellulosic biorefinery. It is the means by which raw biomass from the field or forest is mechanically transformed into an on-spec feedstock with characteristics better suited for the fuel conversion process. **Results:** This work provides a general overview of the objectives and methodologies of mechanical preprocessing and then presents experimental results illustrating improved size reduction via optimization of hammer mill configuration, improved size reduction via pneumatic-assisted hammer milling and improved control of particle size and particle-size distribution through proper selection of grinder process parameters. **Conclusion:** Optimal grinder configuration for maximal process throughput and efficiency is strongly dependent on feedstock type and properties, such as moisture content. Tests conducted using a HG200 hammer grinder indicate that tip speed, screen size and optimizing hammer geometry can increase grinder throughput as much as 400%.

Background

Mechanical preprocessing is the first step in taking herbaceous feedstocks, typically in baled format, or woody feedstocks in log or slash format, from the harvesting location and chopping, shredding, grinding, chipping or otherwise size reducing the material in preparation to supply the feedstock for a lignocellulosic biorefinery. However, current understanding accepts that the characteristics of raw biomass are unable to meet the requirements of both logistic and fuel conversion systems and must be upgraded prior to delivery at the biorefinery plant gate [1].

Mechanical preprocessing is widely considered crucial to the success of a large-scale lignocellulosic fuel industry, and its operations are often placed early in the supply system to maximize system performance and preserve feedstock quality [2–4]. Important features of mechanical preprocessing include low capital and operational costs and efficacy on a wide range of materials.

The objectives of mechanical preprocessing can be summarized as the production of feedstock materials with at least the following five characteristics:

- High mass density for efficient storage and transportation;
- Flowability as a bulk granular solid;
- High aerobic stability to minimize mass and energy losses during storage;
- High conversion efficiencies (i.e., low recalcitrance);
- Easily separable into components with different values/chemical compositions.

These characteristics are inter-related and are impacted in different ways by a wide array of preprocessing operations at all levels within the feedstock supply system. This paper discusses these characteristics in relation to common mechanical preprocessing technologies and the growing biofuels industry and focuses on two technology pathways for mechanical preprocessing:

- Size reduction: or '**comminution**', to facilitate material handling, aerobic stability and conversion efficiency (i.e., low recalcitrance);

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Key terms

Mechanical preprocessing: First step in taking herbaceous or woody feedstocks from harvest format to a size-reduced format suitable for supplying a biorefinery.

Comminution: Breaking, chopping or grinding of larger objects into smaller particles.

Fractionation: Occurrence of deconstructed fractions partitioning by size or density.

Grinding energy: Actual work energy that goes into a grinding process per unit quantity of processed material, including drive chain inefficiencies, electrical power factor losses and friction.

- Mechanical separation: or '**fractionation**', to separate target constituents from bulk material [5].

Within mechanical preprocessing, size reduction is often the process by which the desired feedstock characteristics are achieved. For example, comminution to particle sizes of 1–2 mm, which is necessary for biochemical conversion [6], fast pyrolysis [7] or gasification [8], not only generates new surface area for improved heat transfer and microorganism access [9], but it also releases dissolved organic components [10] and opens material structures that impede microbial and acid attack [9,11]. Size reduction has also been shown to decrease recalcitrance by reducing the degree of polymerization and cellulose crystallinity [10]. Importantly, size-reduction technologies result in increased material density because smaller particles more easily fill void spaces and increase packing density. In addition, small and relatively smoother particles that result from comminution typically have improved material handling characteristics and, in some cases, can be handled very efficiently in equipment designed for bulk grains. Lastly, the comminution process can provide a means to mechanically separate, or fractionate, biomass materials so that high- or low-value constituents can be separated for different end uses. This paper discusses mechanical preprocessing studies undertaken with the objectives to demonstrate improved efficiency and capacity in size reduction via optimization of hammer mill configuration and show improved control of particle size and particle-size distribution through proper selection of grinder process parameters. The following sections discuss some of the more common methods of size reduction and fractionation within the industry.

Size reduction

The most common mechanical preprocessing technologies focus on size reduction and include hammer and knife milling/grinding, chipping, shredding and ball roller milling. It must be remembered, however, that although these technologies are the most widely used, they are not necessarily the most efficient and can consume more than 30% of the energy required to convert biomass to ethanol [12]. For certain materials, other approaches such as veneering and knife shearing have demonstrated far greater efficiencies.

The first stage in the size reduction process is to break up the feedstock (baled biomass or bulky logs) into a format that can be handled more easily by downstream milling operations. Typically tub grinders, horizontal grinders/shredders, bale busters or, in the case of wood, chippers, are used to perform this first-stage size reduction. These first-stage grinders or shredders have large rotating drums with large blunt hammers that quickly shear or shred the material into a less dense, loose format that can be easily milled to the desired size. Large screens are generally used in first-stage grinding to prevent oversized material from exiting the grinding chamber. These screens generally range in size from 2 inch (5 cm) to 6 inch (15 cm) openings. Alternatively, for woody material, chipping is also a common practice. Chippers typically use rotating drums with fixed knives parallel to the drum axis. Chip size is generally controlled by feed rate. The chip size can range from approximately 2 inches (5 cm) down to less than 0.25 inches (0.6 cm) in size.

Once the first-stage grinding or chipping is completed, the feedstock is milled to the desired particle size. Hammer mills are common equipment for this stage of mechanical preprocessing. Hammer mills use large rotating drums with protruding metal bars (i.e., hammers) that impact the material at high velocity to shatter and tear material particles. Typically, the metal bars swing freely from the drum, but fixed hammers are also common in hammer mill designs. Hammer mills are recognized as technology capable of finely grinding the greatest variety of materials [3,13] and are noted for achieving high size-reduction ratios and yielding cubic-shaped particles [14,15]. Hammer mills have a wide application in biomass size reduction because of their simple design, ruggedness and versatility [16]. Fine or especially difficult to grind materials are often best comminuted using high-speed hammer mills with small diameter rotors [3]. High tip speeds result in material striking the outlet screen at steep angles, while slower speeds result in material trajectories more perpendicular to the screen, allowing greater amounts of coarse particles to pass through [17]. As the size of the screen opening impacts the size of particles produced, it also impacts the energy required to produce the particles such that decreasing the size of the screen openings increases the energy consumed in the process [2]. Furthermore, an increase in material moisture also increases the energy consumed to size reduce the material [2].

In a study conducted by Yancey *et al.*, **grinding energy** and particle size were compared at varying feedstock moisture contents [4]. Grinding energy for corn stover, switchgrass and wheat straw were compared at moisture contents of 10–25% in 5% increments. Grinding energy for corn stover and switchgrass showed a steep increase in grinding energy as moisture increased. Moisture content in straw had less effect on grinding energy, although the same pattern was observed. Operating speed, moisture content and initial particle size appear to be crucial in minimizing effective specific energy requirements for biomass size reduction [4]. Mani *et al.* also reported the negative effect of moisture on grinding energy for straw, corn stover and switchgrass [18].

Other strategies have been tested to improve preprocessing costs and increase productivity. A study by Yancey *et al.* compared the efficiency and capacity of grinding sorghum down to 0.25 inch minus in either a single-stage or two-stage grind [19]. This study showed that energy consumption (kWh/dry ton) decreased by over 40% by using a two-step grinding process as opposed to a single-stage process. Capacity in tons per hour more than doubled, from less than 2 tons per h in a single-stage grind to over 4 tons per hour in a two-stage grind. In this study, bale moisture ranged from 15.2 to 16.8%, showing very little variability in bale moisture; hence, bale moisture was not impacting power consumption or capacity.

Because it has been shown that preprocessing can consume as much as one-third of the energy required to convert biomass into fuel, it is only logical to look for improvements in preprocessing strategies to reduce this high-cost step in the process. There are numerous hammer designs available in industry, variations in hammer mill drum speeds and many combinations of screen selection in multiple stage processes to be considered. In this paper, the authors have investigated screen size, drum speed, hammer design and crop type to determine if there are indeed strategies that can be used to decrease the cost of preprocessing.

Mechanical separation

Mechanical separation, or fractionation, is the process of separating biomass into different anatomical fractions so that each may be used for different purposes. Fractionation techniques are well developed for many harvesting technologies [20]. For example, wheat grain, corn kernels, peas and other crops are routinely separated from the remainder of the plant material during harvest. However, for biomass materials, fractionation can be useful to separate different tissue types that are better suited for divergent conversion pathways or that reduce contaminants that impede conversion performance [21]. Although research in chemical fractionation techniques is well developed, corresponding research in mechanical techniques to fractionate materials is still emerging. More common methods of mechanical separation include trommel screening based on size and density, vibratory screening based on particle size or pneumatic separation based primarily on density.

Trommel screening methods are very mature with several references dating back to the 1950s, 1960s and 1970s. This technology moves and separates material through an inclined, rotating circular drum. The rotational movement advances the material across screens for size separation and down the length of the screen by gravity for oversized discharge. The rotation of the screens tend to be more self-cleaning as lodged particles drop free from gravity when rotated upside down.

Flat vibratory screens are generally less effective than trommel screens since particles tend to plug the screen openings unless there is a method to mechanically or pneumatically clean the openings [22]. Vibratory screens, however, do work well for materials that are round to cubic in shape as opposed to long and slender [23]. Long and slender or high aspect ratio particles tend to be the primary cause of plugging as they can form mats and prevent movement through the screens. Beyond plugging, however, long and slender particles also tend to 'spear' or longitudinally fall through the screen openings even when the length of the particle is much longer than the actual size of the screen opening. This behavior significantly reduces the accuracy of the separation process.

Finally, pneumatic separation can be effective for certain size fractions based on the aerodynamic characteristics of the material, impacted by particle size, shape and density [24–26]. The accuracy of pneumatic separation can be negatively affected by moisture as the particles tend to adhere to each other and the screens causing clumping and plugging [27].

Experimental methods & materials

Energy-intensive mechanical preprocessing operations such as grinding or shredding tend to be expensive relative to the low-value feedstock that they produce. This study investigates optimization opportunities to reduce capital and operating costs associated with biomass comminution. Two aspects of mechanical preprocessing are considered: improved size reduction via optimization of hammer mill configuration and the effect of screen selection on particle size.

In order to evaluate improvements to the size reduction process, hammer mill grinding tests were conducted using a small-scale commercial grinder with a nominal power rating of 85 hp (63.4 kW). This scale of testing is ideal to evaluate the effects of grinder configuration and process parameters on grinder capacity and efficiency. The manufactured revolutions per minute of the grinding drum in this grinder is 1930 revolutions per minute. A 1.25-inch hexagonal screen was used for the grinding tests comparing hammer type, grinding speed and shear bar tolerance. Fuel consumption was measured for each test by determining the amount of fuel added following each test. The estimated cost of this grinder is US$80,000, and the grinder can be operated by a single operator. The capacity ranged up to 4 tons/h of loose biomass and used approximately 3.75 gallons of diesel per h.

The original drum design of the commercial grinder has ten stationary block-style hammers (Figure 1) and is used as a baseline for this study. Two new hammer designs, which are longer than the standard block-style hammers, were tested in comparison to the baseline commercial configuration. The two new hammer designs also differ from the original hammers in the way they attach to the rotating drum. Because of the proprietary nature of the hammers, the exact dimensions and pictures of the new hammer designs are not provided. However, both new hammer designs changed the number of hammers and changed their speed by modifying the grinding drum and drive pulleys. Finally, the distance between the cutting bar and the hammers was reduced from 0.5 inches (13 mm) to 0.125 inches (3.2 mm) to increase the initial shear force imposed as the hammers pass by the cutting bar.

Three feedstocks were selected for the study: corn stover, switchgrass and wheat straw. These three feedstocks are three of the more frequently considered feedstocks in the bioenergy industry because of their availability in the USA. The corn stover was grown near Emmitsburgh (IA, USA) in Palo Alto County, and was baled in 3 × 4 × 8-ft bales. The switchgrass was grown near Guymon (OK, USA) in Texas County and was baled in 3 × 4 × 8-ft bales. The wheat straw was harvested in southeast Idaho near Terreton (ID, USA) in Jefferson County, and baled in 4 × 4 × 8-ft bales. Moisture content was measured by determining moisture loss at 103°C for 24 h (American Society of Agricultural Engineers S358.2) (Table 1).

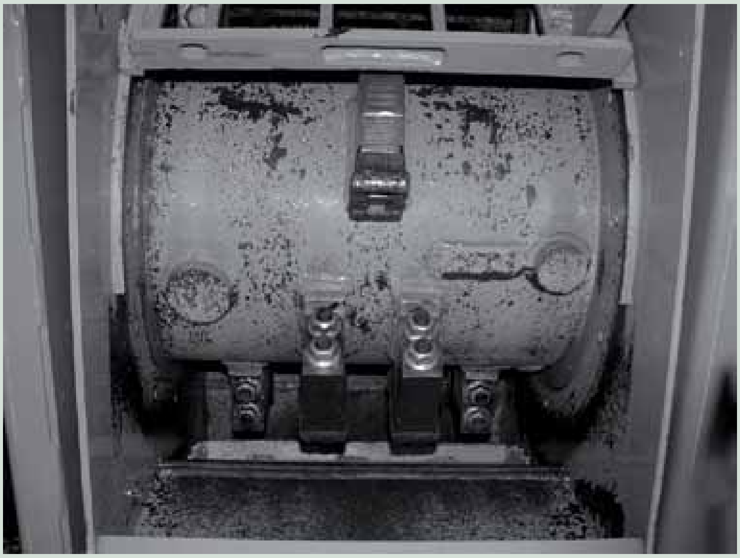

Figure 1. Original hammers in the small-scale grinder.

The infeed of the small-scale grinder is a 18 × 18-inch square. As the bales are much larger than the throat inlet, the material was fed manually from the bale using pitch forks. While every attempt to eliminate human factors from impacting the feed rate of the grinder, it should be noted that human factors cannot be eliminated entirely.

The final test with the small-scale grinder experiments was conducted by changing the clearance of the hammer to the shear bar. With the original hammer design, the hammers do not pass closer than 0.375 inches to the shear bar. Using the new shear bar and the hammer 2 design, the distance of the hammer to shear bar was decreased to 0.125 inches.

Controlling particle-size distribution was evaluated using a full-scale tub grinder as opposed to the small-scale horizontal grinder previously discussed. The tub grinder has a nominal power rating of 540 hp (403 kW). A primary advantage of using a tub grinder is it allows for both large round and large square bale formats as inputs to the grinding chamber, whereas a horizontal grinder is generally limited by the throat dimensions of the in-feed. Testing with the tub grinder focused on processing biomass through a series of screens with different sized openings. The purpose of testing with each screen was to determine the combined impact grinding forces – both impact and shear – and the residence time of the biomass in the grinder chamber on particle-size distribution. Although the grinder for this part of the study was much larger than the one used to evaluate performance parameters, the same stationary block-style hammers were used (Figure 1).

Four different feedstocks were selected for the study: corn stover, switchgrass, *Miscanthus* and sorghum stover. These four feedstocks provided a rather large variety of stalk structure and anticipated deconstruction characteristics. They are also being broadly considered as viable feedstocks for the bioenergy industry in the USA. The corn stover and switchgrass was grown near Centerville (IA, USA) in Appanoose County, and was baled in 4 × 6-ft round bales. The sorghum stover was grown near Otley (IA, USA) in Marion County and baled in 4 × 6-ft round bales. The *Miscanthus* was grown in research plots near Champaign (IL, USA) in Champaign County and was baled in 4 × 4 × 8-ft bales.

Results & discussion

The results are presented in two sections: improved size reduction via optimization of hammer mill configuration, and improved control of particle size and

Table 1. Moisture content of feedstock tested.

Feedstock	Moisture content of processed feedstock (% moisture, wet basis)				
	Original block-style hammers	Long hammer 1	Long hammer 2	Long hammer 2, changed RPM	Long hammer 2, changed RPM, modified shear
Corn stover	6.60	11.85	11.87	6.98	6.99
Switchgrass	9.55	18.30	7.71	7.56	6.62
Wheat straw	10.52	8.72	8.16	8.44	8.96

RPM: Revolutions per minute.

particle-size distribution through proper selection of grinder process parameters.

Improved size reduction via optimization of hammer configuration

A baseline capacity and efficiency was determined using standard block-style fixed cutters (see data labeled 'original hammer' in Figure 2) and screen size (1.25 inches). Two modifications were made to the baseline hammer design to determine if improvements in efficiency and capacity could be achieved. Each new design used loner hammers that attached to the rotating drum differently from each other and the original design. Details about the hammers have been omitted to protect the proprietary nature of the design. The process parameters included hammer tip speed and shear plate tolerance. Capacity was measured in dry matter ton per hour, and efficiency was measured in dry matter ton processed per gallon fuel consumed.

Grinder capacities for the three hammer configurations and three feedstock varieties (switchgrass, corn stover and wheat straw) are shown in Figure 2. Although the results are mixed when comparing the hammer 1 and hammer 2 designs, the new hammer configurations showed significant improvements over the original hammers. Overall, hammer 2 produced the best improvements in grinder capacity, with an average improvement of 200%. Although the hammer 1 design did not perform as well as the baseline hammer for switchgrass, it is likely that the moisture content caused the decrease in performance rather than the hammer type. The moisture content of the switchgrass ground using the

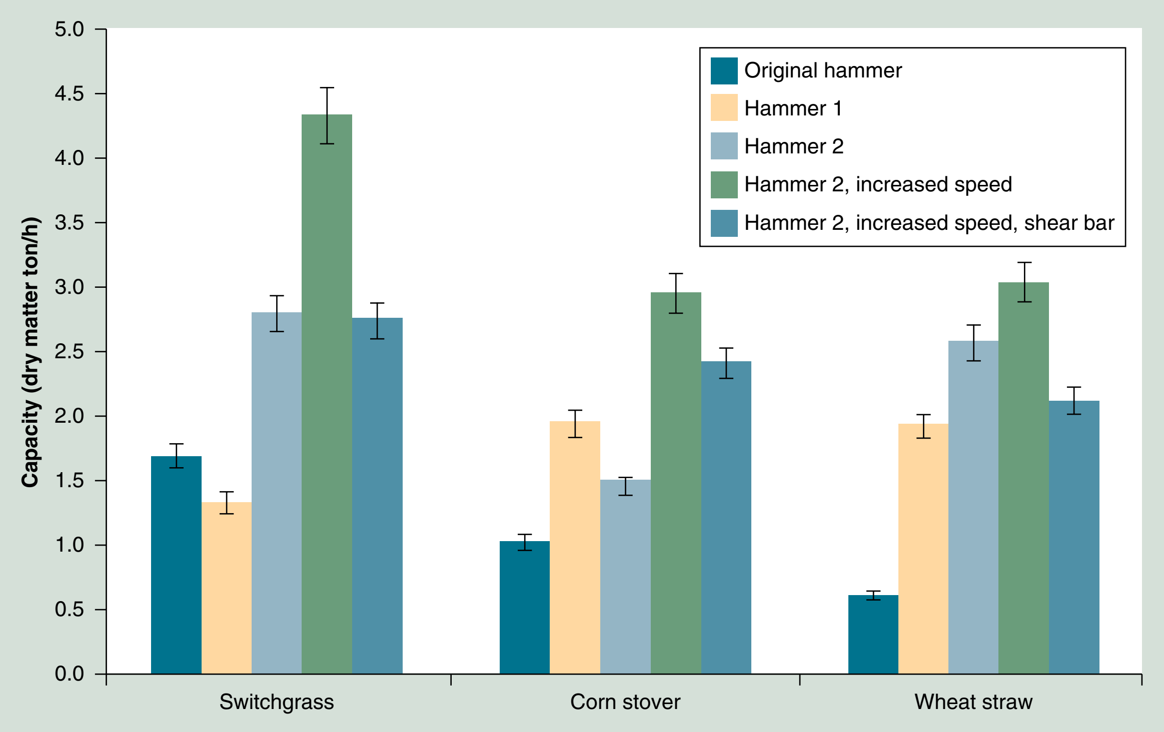

Figure 2. Grinder capacity with 1.25-inch screen for three feedstock varieties preprocessed using three hammer configurations, changing tip speed and addition of a new shear bar. For all feedstock varieties, the hammer 2 configuration operated at changing speed resulted in the greatest increase in grinder capacity.

hammer 1 design was twice that of the other switchgrass tests (Table 1). Based on other studies previously discussed, increasing moisture content results in increased grinding energy requirements [4]. Also, given the physical characteristics of the three crops, one would expect that straw and switchgrass would act similarly as both are grasses. Corn stover, on the other hand, tends to be more fibrous, and the expectation is that the more fibrous the feedstock, the more grinding energy required.

Because it appeared that overall, hammer 2 provided the most significant improvement to performance, hammer 2 was used to evaluate two additional grinder modifications, namely an increase in tip speed and a combined increase in tip speed and tighter tolerance between hammers and shear plate. Changing the tip speed improved grinder capacity for all feedstocks, but reducing the gap between the shear plate and the hammers decreased grinder capacity compared with tip speed alone. Combined uncertainty from process time and feedstock weight measurements is estimated to be less than 5% of the reported values and is represented as error bars in Figure 2 (due to cost constraints, additional test runs were not performed to further validate experimental uncertainties and explore additional combinations of hammers and feedstocks).

The hammer 2 configuration also demonstrated the greatest improvements in grinder efficiency (Figure 3). While the change in tip speed clearly increased grinder capacity for all feedstocks tested (Figure 2), the effect of tip speed on efficiency is not as clear, with most of the results being well within the estimated uncertainty of the measurements. There are advantages and disadvantages to changing the drum speed of a grinder. In many cases, it may not be even possible to alter the drum speed either faster or slower. Changing the drum speed can change the particle-size distribution of the material produced. Speeding up the drum will change the forces on the hammers and the drum and should only be attempted after a thorough investigation into the engineering design of the grinder. In this case, it was assumed that the corn stover and switchgrass tend to be more fibrous than straw and, therefore, a greater benefit was observed relative to grinding energy for corn stover and switchgrass than for straw.

Decreasing the shear plate tolerance generally resulted in a reduction of both capacity and efficiency. Interestingly, the effect of tip speed on efficiency appears to be much greater for corn stover than for switchgrass or wheat straw, while the effect of shear plate tolerance appears to be much greater for switchgrass and wheat

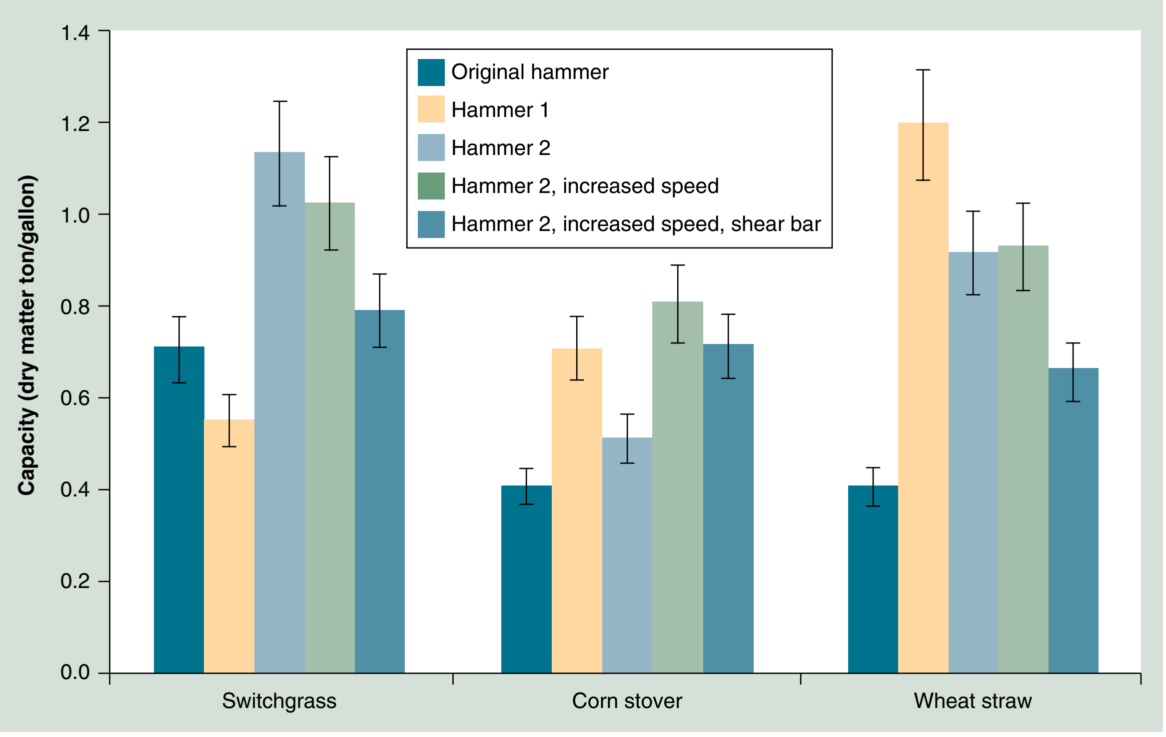

Figure 3. Grinder efficiency with 1.25-inch screen for three feedstock varieties preprocessed using three hammer configurations, changed tip speed and addition of a new shear bar. Despite the increased capacity resulting from the hammer 2 configuration operated at changed tip speed, efficiency was highly variable among all hammer configurations, depending on feedstock type.

straw than for corn stover. This may be attributed to the more aggressive grinding conditions being beneficial to break up the fibrous 'birds nesting' typical of ground corn stover. Taking into account both grinder capacity and efficiency, the best overall performance was achieved with hammer 2 at the higher tip speed. However, neither hammer 1 nor hammer 2 excelled over the other for all feedstocks tested, indicating that feedstock type must be considered during grinder optimization.

The effect of screen selection on particle size

In addition to the economics of size reduction, consideration must also be given to product characteristics. One key characteristic of ground biomass feedstocks is particle-size distribution, primarily related to the amount of fines. Excessive fines can cause problems ranging from fugitive dust issues during handling to problems with chemical penetration in excessively dense packed bed reactors.

Research conducted at Idaho National Laboratory (INL) is focused on understanding the relationships between material properties (moisture content, physiological structure and so on), grinder process parameters (screen size, hammer speed and so on), and product particle-size distribution. In this study, biomass deconstruction in a hammer mill was studied to understand the relationship of grinding forces – both impact and shear – as well as residence time in the grinder on particle-size distribution. A high-speed camera was used to qualitatively evaluate the deconstruction process in a hammer mill grinder (Figure 4). High-speed video analysis revealed that fines generation in hammer mill grinding largely results from nonfibrous tissues that disintegrate into small particles when they are impacted with the rotating hammers and/or fixed shear plates. Fibrous tissues such as the outer rind, leaf and husk from corn stover remain intact upon impact, and require shear forces to break them up before exiting the grinder. Given these deconstruction mechanisms, a noticeable quantity of fines is always generated regardless of the screen size at the grinder outlet. Smaller screen sizes were observed to result in more collisions per particle, which resulted in a reduction of the maximum particle size exiting the grinder and also an increase in the amount of fines.

This deconstructive process was demonstrated in a test conducted by INL using a range of screen sizes in a commercial tub grinder. *Miscanthus* was ground through a commercial grinder configured with different screen sizes ranging from no-screen (7-inch rectangular opening) to a 1-inch round screen. The resulting materials were then separated using a series

Figure 4. Deconstruction process in a hammer mill grinder.

of sieves [23]. In the first case, the grinder screen was removed so that the *Miscanthus* pieces would experience a minimal number of collisions before passing out of the grinder. This configuration resulted in many large particles with over 35% of the original mass associated with particles that would not pass through a 0.75-inch sieve (see tray 2, 0.75 inch bar in the no screen section of Figure 5), while only 5% of the original mass was reduced to particles that passed through the smallest sieve with 0.08-inch openings (see no screen section of Figure 5). Inserting a 6-inch screen in the grinder dramatically reduced the quantity of material retained on the 0.75-inch sieve. The amount of large particles continued to decrease with decreasing screen size, and an associated increase of smaller particles as evidenced in Figure 5 by the distributions in the 4-inch round, 2-inch square and 1-inch round sections.

The same series of tests was performed with corn stover, wheat straw and switchgrass, with the same trends and general distributions as shown with *Miscanthus*. These results demonstrate the ability to influence the amount and size of different fractions produced with commercial scale grinders by simply controlling the size of the openings in the screens. Factors such as feedstock type have an impact on the absolute quantities of different sized particles, but generally show the same trends. However, as discussed in the previous section, the size of the screen openings significantly change the performance of the grinder in terms of capacity and efficiency, and must be considered when the overall process is evaluated. What is generally true is that product quality, or the potential to add value to the resulting ground material, is often underestimated and the potential to trade-off lower machine capacities and efficiencies for higher valued material is not understood. Thus, the means

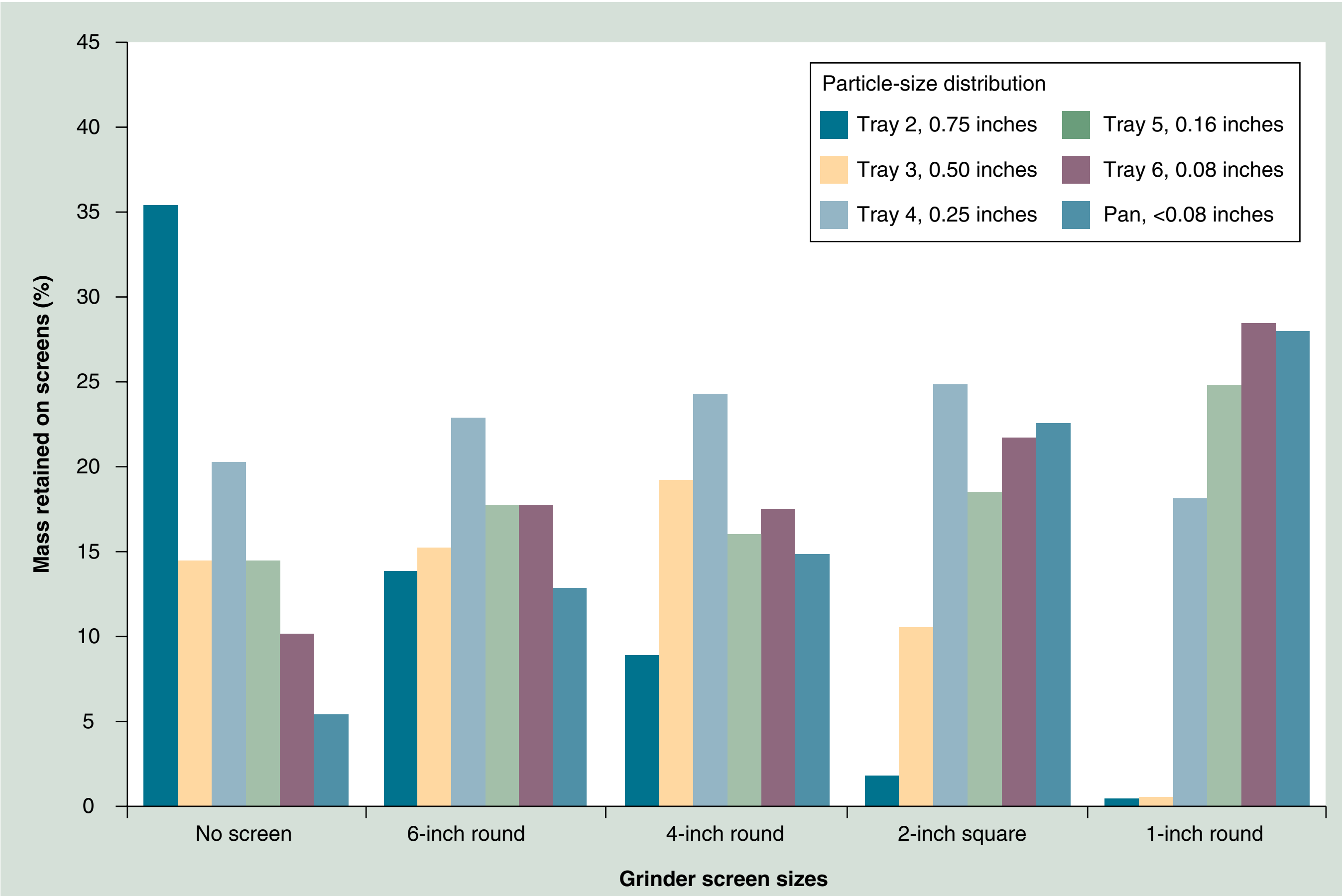

Figure 5. ***Miscanthus*** **particle-size distributions after hammer mill grinding operations with no screen in hammer mill and with screens of 6-, 4-, 2- and 1-inch round openings.**

of balancing machine performance with product quality and value can be captured through fractionation, which is the partitioning of deconstructed fractions by composition.

Fractionation requires that the material first be deconstructed into components that have diverse physical properties (e.g., particle size, density and so on) such that the products can be subsequently separated. One advantage of separating material based on particle size is the removal of unwanted fractions of biomass. Literature and preliminary work at INL indicate that fractions of fine particles often have higher ash content [28–30]. Because the fines typically represent only a small portion of the total biomass weight, it is possible to remove a substantial portion of the ash content while only losing a small amount of overall mass. A reduction in ash content is desirable for both thermochemical and biochemical conversion processes.

By understanding the biochemical composition of each size fraction, users can better determine the feasibilty of separating specific size fractions during preprocessing to minimize unwanted fractions or separating fractions based on distinct marketable products. Based on studies that indicate that a high ash content occurs in the fines, a separation process can be developed to remove fines (<0.08 inches). While moisture has a negative impact on performance, it also impacts the ability to separate using various separation techniques [31].

Conclusion

Mechanical preprocessing operations and equipment are more cost-effective if they can handle a wide variety of materials. Equipment throughput (material processed per hour), cost and energy consumption are important factors for all operations. Moisture content is an important factor for typical grinding operations because increases in moisture correlate to grinding capacity and efficiency decreases. Fractional deconstruction has very promising possibilities for subsequent conversion; however, the economics for industrial-scale fractional deconstruction have not yet been determined. This work demonstrated that modifying the hammers of a small-scale grinder resulted in increased capacity and efficiency. Changing the tip speed in this case also resulted in a net improvement over the original speed of the hammer mill by as much as 300%. Decreasing the tolerance between the sheer bar and the hammers had a negative effect on capacity and efficiency.

Results obtained using this relatively small 85 hp diesel grinder are indicative of what might happen at a larger scale, although it should not be assumed that the scale-up to a larger grinder is linear. While changing the tip speed of the grinder is possible in some cases, it may not be feasible to modify the drum speed on all grinders. It is very important to note that an increase in tip speed will also increase the forces within the grinding drum and hammers. Thus, before modifying the speed of any grinder, an analysis should be performed to ensure safe operating conditions still exist.

At full scale, testing showed that even when large screens are used, fines are going to be produced. Of course, the smaller the screens used the more fines are generated. There can be benefits obtained by understanding the differences in biochemical composition of the fines versus the bulk material and then determining methods to separated material based on particle size. Ash content is generally greater in the fines. Separation of the fines from the bulk could result in a product that more easily meets industry standards relative to ash content.

Future perspective

It is well understood that the physical characteristics of different biomass materials will make the development of a single robust mechanical preprocessing system challenging. Simultaneously addressing equipment capacity, efficiency, cost and energy consumption along with biomass physical and chemical quality is part of the research moving forward. Although mechanical preprocessing is centered on distributed preprocessing concepts, it includes other critical elements such as production, harvest and collection, storage, and transportation and handling, as key influencing technologies. Thus, integrated research, development and demonstration must be employed to account for different biomass types, formats and characteristics, in order to optimize supply system processes such as grinding and fractionation operations.

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No writing assistance was utilized in the production of this manuscript.

Executive summary

Background

- Mechanical preprocessing is one of the primary operations in the feedstock supply system for a lignocellulosic biorefinery.
- Mechanical preprocessing is the means by which raw biomass from the field or forest is mechanically transformed into an on-spec feedstock with characteristics better suited for the fuel conversion process.

Results

- This work provides a general overview of the objectives and methodologies of mechanical preprocessing.
- This work presents experimental results illustrating improved size reduction via optimization of hammer mill configuration and improved control of particle size and particle-size distribution through proper selection of grinder process parameters.

Conclusion

- Optimal grinder configuration for maximal process throughput and efficiency is strongly dependent on feedstock type and properties, such as moisture content.
- Tests conducted using a small-scale grinder indicate that changing the tip speed increases throughput and efficiency.
- Hammer design and configuration has a strong influence on increasing grinder performance.

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- ■ of interest
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